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The Mass and Width of the W Boson

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THE MASS AND WIDTH OF THE W BOSON

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The Tevatron and LEP2 experiments presently provide the most precise direct determinations of the mass and width of the W boson. The combined results are : Mw = 80.394 ± 0.042 GeV and Γ_W = 2.095 ± 0.106 GeV. The results are in excellent agreement with the predictions of the Standard Model. In this article the latest results are described and the systematic errors which could limit further significant improvements in the precision of these measurements are reviewed.

1 Introduction

A precise W mass measurement allows a stringent test of the Standard Model (SM) beyond tree level where radiative corrections lead to a dependence of the W mass on both the top quark mass and the mass of the, as yet unobserved, Higgs boson. The dependence of the radiative corrections on the Higgs mass is only logarithmic whilst the dependence on the top mass is quadratic. Simultaneous measurements of the W and top masses can thus ultimately serve to further constrain the Higgs mass beyond the LEP1/SLD limits and potentially indicate the existence of particles beyond the SM. Similarly, non SM decays of the W would change the width of the W boson. A precise measurement of the W width can therefore be used to place constraints on physics beyond the SM. The latest results on the W mass from the LEP2 and Tevatron experiments are now of such a precision that the uncertainty on the top mass [1] is beginning to become the limiting factor in predicting the mass of the Higgs boson.

The results described in this article are from the LEP experiments with data taken above the WW production threshold in e^+e^- collisions at $\sqrt{s} = 161-189$ GeV and from the two Tevatron experiments with data taken at $\sqrt{s} = 1.8$ TeV from $p\bar{p}$ collisions. Significant improvements in the statistical error of these measurements is anticipated since the LEP2 experiments are continuing to take data in the range $192 < \sqrt{s} < 202$ GeV and the Tevatron experiments resume data taking in the year 2000 at $\sqrt{s} = 2.0$ TeV. However, the precision of both sets of measurements are now becoming limited by systematic uncertainties. Further progress will need to be made in the understanding of various issues for a significant improvement in the precision of these results to be realised.

2 Data Samples and Event Selection

The first observation and measurements of the W boson were made at the CERN SpS by the UA1 and UA2 experiments [2]. These measurements were based on modest event samples ($\sim 4k$ events) and integrated luminosity (12 pb^{-1}). Since that time the Tevatron and LEP2 experiments have recorded over 1 fb^{-1} of W data. The Tevatron experiments have the largest sample of W events : over 180,000 from a combined integrated luminosity of $\sim$ 220 pb^{-1}. The LEP experiments, despite a very large integrated luminosity ($\sim$ 15000 pb^{-1} total across all experiments), have event samples substantially smaller than the Tevatron experiments. The LEP2 results presented here are based on event samples of $\sim 6k$ events per experiment. However, despite the smaller statistics of the event sample in comparison to the Tevatron experiments, the LEP2 experiments ultimately achieve a comparable precision. On an event by event basis, the LEP2 events have more information; in particular the LEP2 experiments can impose energy and momentum constraints because they have a precise knowledge of the initial state through the beam energy measurement. The NuTeV experiment [3] at FNAL also has a large sample ($\sim 10^6$) of charged current events mediated by the exchange of a W-boson. This allows an indirect determination of the W mass through a measurement of $\sin^2\theta_{\rm w}$. This is done by comparing the neutral and charged current cross sections in νFe and $\overline{\nu}$Fe collisions. In this article only the direct determinations of the W mass and width from LEP2 and the Tevatron will be discussed.

3 Mass Measurement : Method

At LEP2, W bosons are produced in pairs though s-channel Z or γ exchange or by t-channel neutrino exchange. These three production channels are referred to as the CC03 channels. The other small non-CC03 contributions to the measured cross section are corrected for by Monte-Carlo such that the data can be directly compared to the CC03 predictions. The W pairs decay 46% of the time to a purely hadronic final-state, 44% of the time to a semi-leptonic final state, i.e. where one W decays to qq' and the other to $l\nu$ and 10% of the time to a purely leptonic final state. Leptons are detected in all three flavours : electron, muon and tau. The W mass at LEP2 has been measured by two methods :

- Through a measurement of the WW cross section at threshold i.e. $\sqrt{s} =$ 161 GeV.
- By explicit reconstruction of the invariant masses of the two W bosons.

The first measurement has a small systematic error and its error is entirely dominated by the statistical uncertainty. Ultimately, given a sufficient amount of integrated luminosity, this is the most precise method for determining the W mass.

At the Tevatron W bosons are predominantly produced singly by quark anti-quark annihilation. The quarks involved are mostly valence quarks becauase the Tevatron is a $p\bar{p}$ machine and the x values involved in W production ($0.01 \lesssim x \lesssim 0.1$) are relatively high. The W bosons are only detected in their decays to $e\nu$ (CDF and DØ) and $\mu\nu$ (CDF only) since the decay to qq' is swamped by the QCD dijet background whose cross section is over an order of magnitude higher in the mass range of interest. At the Tevatron one does not know the event $\hat{s}$ and one cannot determine the longitudinal neutrino momentum since a significant fraction of the products from the $p\bar{p}$ interaction are emitted at large rapidity where there is no instrumentation. Consequently, one must determine the W mass from transverse quantities [4] namely : the transverse mass (M_T), the charged lepton P_T (P_T^l) or the missing transverse energy ($\not{E}_\mathrm{T}$). $\not{E}_\mathrm{T}$ is inferred from a measurement of $\mathrm{P}_\mathrm{T}^{l}$ and the remaining P_T in the detector, denoted by $\vec{\mathrm{U}}$ i.e.

$$\vec{\not{E}}_\mathrm{T} = -(\vec{\mathrm{U}} + \vec{\mathrm{P}}_\mathrm{T}^{l}) \qquad \text{and } \mathrm{M}_\mathrm{T} \text{ is defined as}$$

$$\mathrm{M}_\mathrm{T} = \sqrt{2\mathrm{P}_\mathrm{T}^{l}\not{E}_\mathrm{T}(1-\cos\phi)} \qquad \text{where } \phi \text{ is the angle between } \vec{\not{E}}_\mathrm{T} \text{ and } \vec{\mathrm{P}}_\mathrm{T}^{l}$$

$\vec{\mathrm{U}}$ receives contributions from two sources. Firstly, the so-called W recoil i.e. the particles arising from initial state QCD radiation from the $q\bar{q}$ legs producing the hard-scatter and secondly contributions from the spectator quarks ($p\bar{p}$ remnants) and additional minimum bias events which occur in the same crossing as the hard scatter. This second contribution is generally referred to as the underlying-event contribution. Experimentally these two contributions cannot be distinguished. Owing to the contribution from the underlying-event, the missing transverse energy resolution has a significant dependence on the instantaneous $p\bar{p}$ luminosity. M_T is to first order independent of the transverse momentum of the W ($\mathrm{P}_\mathrm{T}^\mathrm{W}$) whereas $\mathrm{P}_\mathrm{T}^{l}$ is linearly dependent on $\mathrm{P}_\mathrm{T}^\mathrm{W}$. For this reason, and at the current luminosities where the effect of the $\not{E}_\mathrm{T}$ resolution is not too severe, the transverse mass is the preferred quantity to determine the W mass. However, the W masses determined from the $\mathrm{P}_\mathrm{T}^{l}$ and $\not{E}_\mathrm{T}$ distributions provide important cross-checks on the integrity of the M_T result since the three measurements have different systematic uncertainties.

The systematics of the LEP2 and Tevatron measurements are very different and thus provide welcome complementary determinations of the W mass. The systematics at LEP2 are dominated by the uncertainty in the beam energy (which is used as a constraint in the mass fits) and by the modeling of the hadronic final state, particularly for the events where both W bosons decay hadronically. At the Tevatron, the systematics are dominated by the determination of the charged lepton energy scale and the Monte-Carlo modeling of the W production, in particular its P_T and rapidity distribution. At the Tevatron, one cannot use a beam energy constrain to reduce the sensitivity of the W mass to the absolute energy (E) and momentum (p) calibration of the detector. Any uncertainty in the detector E, p scales thus enters directly as an uncertainty in the Tevatron W mass. This means that the absolute energy and momentum calibration of the detectors must be known to better than 0.01%. By contrast at LEP, an absolute calibration of 0.5 % is sufficient.

4 Tevatron W Mass

The W mass at the Tevatron is determined through a precise simulation of the transverse mass line-shape, which exhibits a Jacobian edge at $\mathrm{M}_\mathrm{T} \sim \mathrm{M}_\mathrm{W}$. The simulation of the line-shape relies on a detailed understanding of the detector response and resolution to both the charged lepton and the recoil particles. This in turn requires a precise simulation of the W production and decay. The similarity in the production mechanism and mass of the W and Z bosons is exploited in the analysis to constrain many of the systematic uncertainties in the W mass analysis. The lepton momentum and energy scales are determined by a comparison of the measured Z mass from $\mathrm{Z} \to \mathrm{e}^+\mathrm{e}^-$ and $\mathrm{Z} \to \mu^+\mu^-$ decays with the value measured at LEP. The simulation of the W P_T and the detector response to it are determined by a measurement of the Z P_T which is determined precisely from the decay leptons and by a comparison of the leptonic (from the Z decay) and non-leptonic E_T quantities in Z events. The reliance on the Z data means that many of the systematic uncertainties in the W mass analyses are determined by the statistics of the Z sample.

The W and Z events in these analyses are selected by demanding a single isolated high P_T charged lepton in conjunction with missing transverse energy (W events) or a second high P_T lepton (Z events). Depending on the analyses, the $\not\!\!E_T$ cuts are either 25 or 30 GeV and the lepton P_T cuts are similarly 25 or 30 GeV. CDF only uses $W \rightarrow e\nu$ and $W \rightarrow \mu\nu$ events [5] in the rapidity region : $|\eta| < 1$, whereas DØ [6] uses $W \rightarrow e\nu$ events out to a rapidity of ~ 2.5. In total $\sim 84k$ events are used in the W mass fits and $\sim 9k$ Z events are used for calibration.

4.1 Lepton Scale Determination

The lepton scales for the analyses are determined by comparing the measured Z masses with the LEP values. The mean lepton P_T in Z events ($P_T \sim 42$ GeV) is ~ 5 GeV higher than in W events, consequently in addition to setting the scale one also needs to determine the non-linearity in the scale determination i.e. to determine whether the scale has any P_T dependence. DØ does this by comparing the Z mass measured with high P_T electrons with J/ψ and π^0 masses measured using low P_T electrons as well as by measuring the Z mass in bins of lepton P_T. In the determination of CDF's momentum scale the non-linearity is constrained using the very large sample of $J/\psi \rightarrow \mu\mu$ and $\Upsilon \rightarrow \mu\mu$ events which span the P_T region : $2 < P_T < 10$ GeV. The non-linearity in the CDF transverse momentum scale is consistent with zero (see Fig. 1). This fact in turn can be exploited to determine the non-linearity in the electron transverse energy scale through a comparison of the measured E/p with a MC simulation of E/p where no E_T non-linearity is included. The lepton scale uncertainties form the largest contribution to the W mass systematic error. The non-linearity contribution to the scale uncertainty is typically $\sim 10\%$ or less.

The Z lineshape is also used by both experiments to determine the charged lepton resolution functions i.e. the non-stochastic contribution to the calorimeter resolution and the curvature tracking resolution in the case of the CDF muon analysis.

4.2 W Production Model

The lepton P_T and $\not\!\!E_T$ distributions are boosted by the non zero P_T^W and the $\not\!\!E_T$ vector is determined in part from the W-recoil products. As such a detailed simulation of the P_T^W spectrum and the detector response and resolution functions is a necessary ingredient in the W mass analysis. The W P_T distribution is determined by a measurement of the Z P_T distribution (measured from the decay leptons) and a theoretical prediction of the W to Z P_T ratio. This ratio is known with a small uncertainty and thus the determination of the W P_T is dominated by the uncertainty arising from the limited size of the Z data sample. The P_T^Z distribution

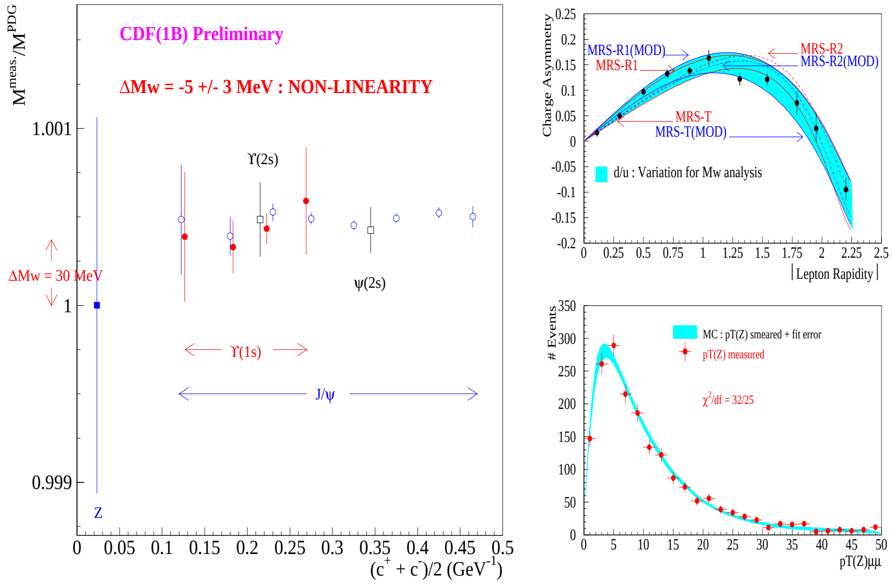

Figure 1. LEFT: The CDF determination of the momentum scale and non-linearity using dimuon resonances. RIGHT UPPER: The modified PDF sets used in the Mw analysis, which span CDF's W charge asymmetry measurement. RIGHT LOWER : The Z P_T distribution as measured by CDF in the $Z \rightarrow \mu^+\mu^-$ channel.

of the CDF $Z \rightarrow \mu^+\mu^-$ sample is shown in Fig. 1. The detector response and resolution functions to the W-recoil and underlying event products are determined by both experiments using Z and minimum bias events. Since the W-recoil products are typically produced along the direction of the vector boson P_T and the underlying event products are produced uniformly in azimuth, the response and resolution functions are determined separately in two projections – one in the plane of the vector boson and one perpendicular to it. Typically one finds the resolution in the plane of the vector boson is poorer owing to the presence of jets (initial state QCD radiation from the quark legs) which are absent in the perpendicular plane where the resolution function matches closely that expected from pure minimum bias events. The parton distribution functions (PDFs) determine the rapidity distribution of the W and hence of the charged lepton. Both experiments impose cuts on the rapidity of the charged lepton and so a reliable simulation of this cut is necessary if the W mass determination is not to be biassed. On average the u quark is found to carry more momentum than the d quark resulting in a charge asymmetry of the produced W i.e. $W^{+(-)}$ are produced preferentially along the $(p\bar{p})$ direction. Since the V-A structure of the W decay is well understood, a measurement of the charged lepton asymmetry therefore serves as a reliable means to constrain the PDFs. To determine the uncertainty in the W mass arising from PDFs, MRS PDFs were modified to span the CDF charged lepton asymmetry measurements [7]. This is illustrated in Fig. 1.

4.3 Mass Fits

The W mass is obtained from a maximum likelihood fit of M_T templates generated at discrete values of M_W with Γ_W fixed at the SM value. The templates also include the background distributions, which are small ($< 5\%$) and have three components : $W \to \tau\nu$, followed by $\tau \to \mu/e\nu\nu$, QCD processes where one mis-measured jet mimics the $\not{E}_T$ signature and the other jet satisfies the charged lepton identification criteria and finally Z events where one of the lepton legs is not detected. The transverse mass fits for the DØ end-cap electrons and the two CDF measurements are shown in Fig. 2. The uncertainties associated with the measurements are listed

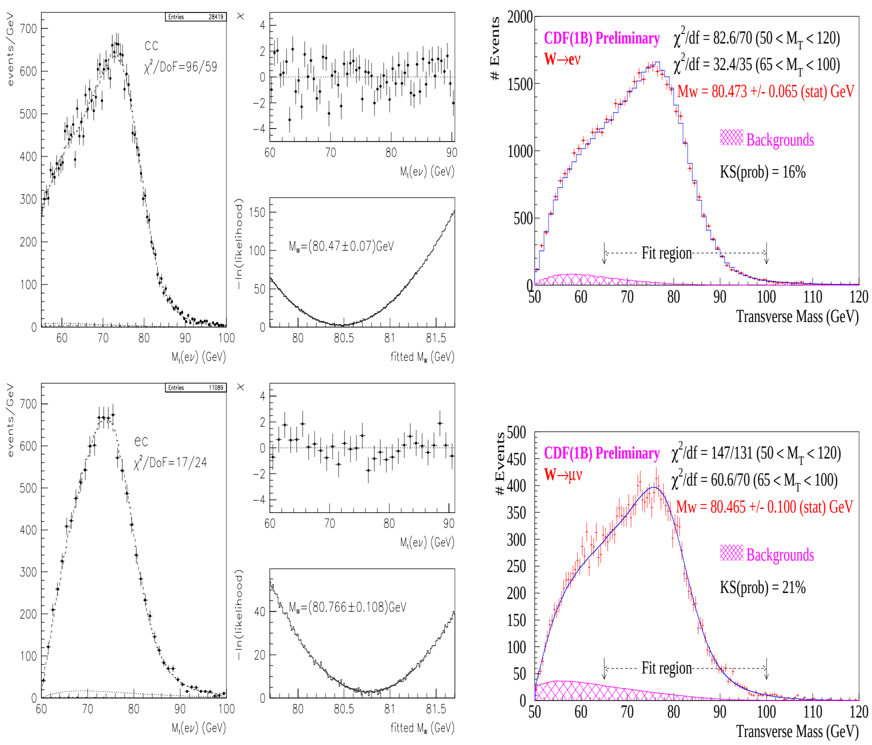

Figure 2. Transverse mass distributions compared to the best fit. LEFT : DØ's published central-electron analysis and preliminary end-cap analysis. RIGHT : CDF's electron and muon channel analyses. The fit likelihood and residuals are also shown for the two DØ distributions.

in Table 1. The uncertainties of the published DØ central-electron analysis are also listed. For both experiments the largest errors are statistical in nature, both from the statistics of the W sample and also the statistics of the Z samples which are used to define many of the systematic uncertainties e.g. the uncertainties in the lepton energy/momentum scales and the W P_T model. The CDF and DØ

Error Source	DØ (C)	DØ (EC)	CDF (e)	CDF (μ)
Statistical	70	105	65	100
Lepton Scale+Resolution	70	185	80	90
$P_T^W + \not{E}_T$ Model	35	50	40	40
Other experimental	40	60	5	30
Theory (PDFs, QED)	30	40	25	20
Total Error	120	235	113	143
Mass Value	80.440	80.766	80.473	80.465
Combined Mass Values	80.497 ± 0.098 GeV		80.470 ± 0.089 GeV	

Table 1. The mass values and uncertainties of the CDF and DØ W mass analyses using the 1994–1995 data. The uncertainties are quoted in MeV. The mass values when the 1992–1993 data are included become : 80.474 ± 0.093 GeV for DØ and 80.430 ± 0.079 GeV for CDF. (EC) denotes the large rapidity end-cap analysis and (C) denotes the central rapidity analysis.

measurements are combined with a 25 MeV common uncertainty which accounts for the uncertainties in PDFs and QED radiative corrections which by virtue of being constrained from the same source are highly correlated. Together the two experiments yield a W mass value of 80.450 GeV with an uncertainty of 63 MeV. For the first time, both Tevatron experiments have measurements with uncertainties below 100 MeV and the combined uncertainty is comparable with the LEP2 results described in the next section.

4.4 Future Tevatron W mass measurements

In the next Tevatron run, the statistical size of the W mass event samples will increase by a factor of ~ 25. This means that the statistical part of the Tevatron W mass error in the next run will be ~ 10 MeV, where this also includes the part of the systematic error which is statistical in nature e.g. the determination of the charged lepton E and p scales from Z events. However to obtain reliable estimates for the total Run-II/LHC W mass error, the sources of error which do not scale with statistics need to be carefully evaluated. At present these error sources contribute 25 MeV out of the total Tevatron W mass error of 60 MeV. The four areas where the errors are expected to be dominated by systematic effects (not determined by the statistics of the calibration/control samples) and thus could be the limiting factors in achieving a W mass uncertainty of < 30 MeV are [8] :

- Knowledge of detector non-linearity i.e. the energy and momentum scales determined at the Z mass must be extrapolated to the momentum range relevant to the W mass analysis.
- The model for QCD radiation is derived from Z events and must be extrapolated to W events.
- QED radiative corrections.
- Parton distribution functions.

5 LEP2 Measurement

The first LEP2 W mass determinination [9] was made from a measurement of the WW cross section at the W pair threshold energy ($\sqrt{s} = 161$ GeV). This is shown in figure 3 and yields a W mass of : $80.40\pm^{0.22}_{0.21}$ GeV, where the error is almost entirely due to the statistical error on the cross section measurement.

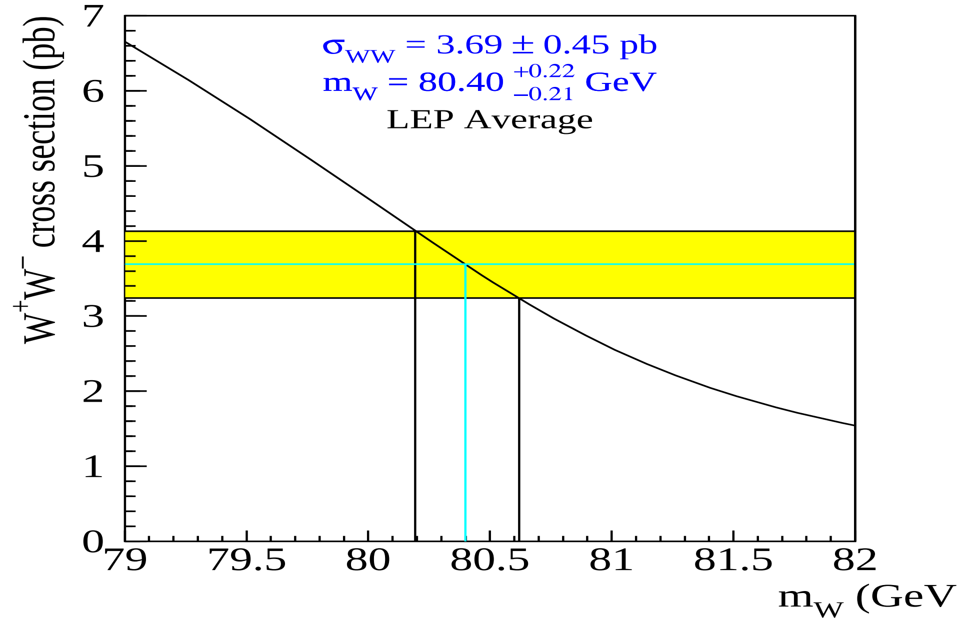

Figure 3. The SM prediction for the $e^+e^- \rightarrow$ WW cross section as a function of the W mass at $\sqrt{s} = 161$ GeV. The LEP2 measurement is shown by the shaded region.

The most precise LEP2 measurements [10] have come from the direct reconstruction of the W invariant mass in the all-hadronic and semi-leptonic decay modes. ALEPH has also recently made a measurement in the all leptonic mode. A comparison of the all-hadronic and semi-leptonic measurements allows valuable cross checks to be made on the integrity of the results because the two measurements have different systematic errors.

In the semi-leptonic analysis, two hadronic jets are selected by the Durham algorithm in addition to the large $\not{E}_T$ and isolated lepton. The lepton selection is generally augmented by imposing additional topological requirements e.g $\cos\theta_{l\nu}$. The backgrounds are small and arise from single W production and also the so-called "radiative return" events. In these events, a hard photon is emitted from the final state such that the sub-process centre of mass energy is returned to the Z-pole where the cross section is large. The $qq'l\nu$ signature is faked by lepton mis-identifiucation or leptons arising from heavy quark decay. The all-hadronic channel event selection makes uses of neural networks to exploit the difference between the 4 quark final state arising from the decay of two Ws in comparsion to the 4 quark configuration arising in radiative-return Z events. In these events one of the quarks produced by the Z radiates a gluon which then undergoes : $g \rightarrow q\bar{q}$. Another complication in the all-hadronic analysis is that one must choose the correct pairings of the jets i.e. one must try and choose the 2 jets from the same W. This is done, for instance in the OPAL analysis, by forming a jet-pairing likelihood which is derived from such quantities as the difference in mass between the possible pairings and the sum of the opening angles in the two pairings. A failure to choose the correct pairing basically removes any sensitivity to the W mass. This is illustrated in figure 4.

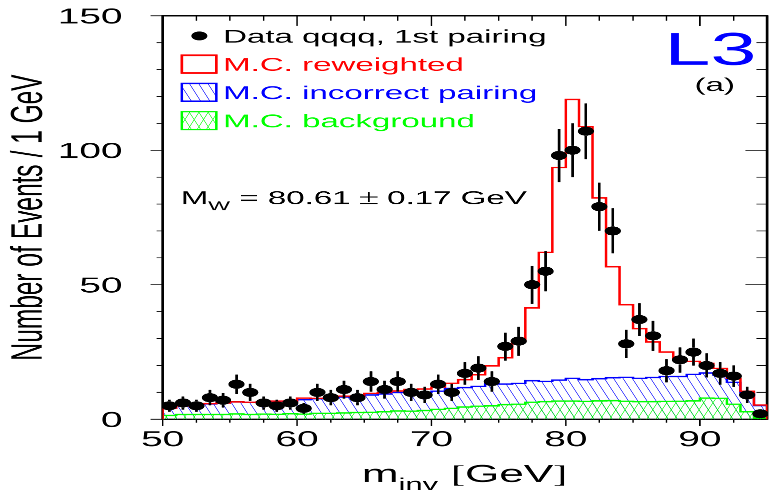

Figure 4. The jet-jet invariant mass distribution for WW → 4q events. Around 15% of the events have an incorrect jet pairing – the mass distribution of which is shown for Monte Carlo events.

After the event selection and preliminary invariant mass measurements, kinematic fits are performed which greatly increase the resolution of the final W mass and reduce the level of background in the events used to extract the W mass. In the semi-leptonic channel, all four experiments require that the W mass from the $l\nu$ and the qq' decays be the same and impose energy and momentum conservation. This results in a 2C fit and yields one mass per event. The details for the all-hadronic channel depend on the experiment e.g. DELPHI permits the presence of a fifth jet and ALEPH rescales the jet masses to the beam energy. Nevertheless, all constraints result in a 4C fit which produce 2 masses per event.

How the event by event masses from the kinematic fit are then used to determine a final W mass for the event sample again varies with each experiment. But broadly speaking two techniques are used :

- A Monte-Carlo re-weighting technique. Large samples of events are generated at a given M_w, Γ_w and are reweighted using the CC03 matrix elements to any M_w, Γ_w such that a likelihood minimisation of the data with respect to M_w and Γ_w can be performed.

- A Monte-Carlo convolution technique. This tends to exploit more information from the events. For each event a 2D probability curve is formed and convoluted with the signal and background probability. The offsets in the resulting mass e.g. due to initial state radiation are corrected in the final result using Monte-Carlo calibrations.

The experiments typically use one method for the published results and the second as a cross check.

5.1 LEP2 Systematics

The LEP2 systematics arise principally from uncertainties in the beam energy, which is used in the kinematic fit and from uncertainties in modelling the hadronic final state. The beam energy has been determined using an extrapolation of the LEP1 resonant depolarisation method. At $\sqrt{s} = 189$ GeV, the W mass error from this source is 18 MeV. This can be cross checked at some level by determining the Z mass in radiative return events (using the beam energy and radiative photon) and comparing it to the very precise value obtained at LEP1.

The systematic error arising from uncertainties in the hadronic fragmentation and final state interactions is presently ~ 30 MeV out of a total systematic error of ~ 45 MeV. The uncertainty in final state interactions are a particular concern for the all-hadronic decay. In this case, since the W lifetime is so small, the 4 quarks are only ~ 0.1 fm apart at production, whereas the fragmentation process takes place over a scale of ~ 1 fm. This means that the two W systems cannot necessarily be considered as independent. Any "cross-talk" between the two systems that is not simulated in the Monte-Carlo can produce a bias in the reconstructed jet angles and thus shift the W mass. Energy shifts are generally less significant because of the imposition of the beam energy constraint. Two effects occuring between the two W systems have been considered. Firstly, colour re-combination effects – non perturbative colour flux tubes extend between the two W systems. Secondly, Bose-Einstein (BE) correlations between the fragmentation products of the two W bosons, whereby there are local enhancements in particle multiplicity. Presently, no strong consensus on these two effects has emerged and thus the systematic errors have been set conservatively. BE correlations have been observed between the fragmentation particles from a single W (in semi-leptonic events), as was the case for Z events, but the experiments are yet to agree on whether the effect is apparent between fragmentation particles from different Ws. DELPHI reports "evidence for BE correlations between different Ws" [11], whilst ALEPH states that they are "disfavoured at the 2.7 σ level" [12] and OPAL concludes that it is "not established whether they exist or not".

In the case of colour re-combination effects, the experiments compare distributions from the hadronically decaying W in the semi-leptonic event sample with the same distribution for Ws in the all-hadronic event. However at the moment, there do not appear to be distributions which, with the present statistical uncertainty, are incisive enough to see the size of effect that the models of colour re-combination predict. For example, by comparing the multiplicity from a single W decay in the two event samples, one finds they are different by 0.1 ± 0.4 whereas the models tend to predict only a difference $\lesssim 0.1$. Regrettably, it appears that the most incisive discriminator of the colour-recombination effects is the W mass itself. At the moment the W mass from the all-hadronic and semi-leptonic event samples differ by 2.1 σ.

This area of final state interactions is potentially the area which could limit further significant improvements in the LEP2 W mass error. With larger statistics and the use of different, more incisive distributions, it is hoped that such effects can be better understood and hence their influence on the W mass minimised.

The LEP2 mass values are compared with the Tevatron values in figure 5. They are in excellent agreement despite being measured in very different ways with widely differing sources of systematic error. These direct measurements are also in very good agreement with the indirect measurement from NuTeV and the prediction based on fits to existing, non W, electroweak data.

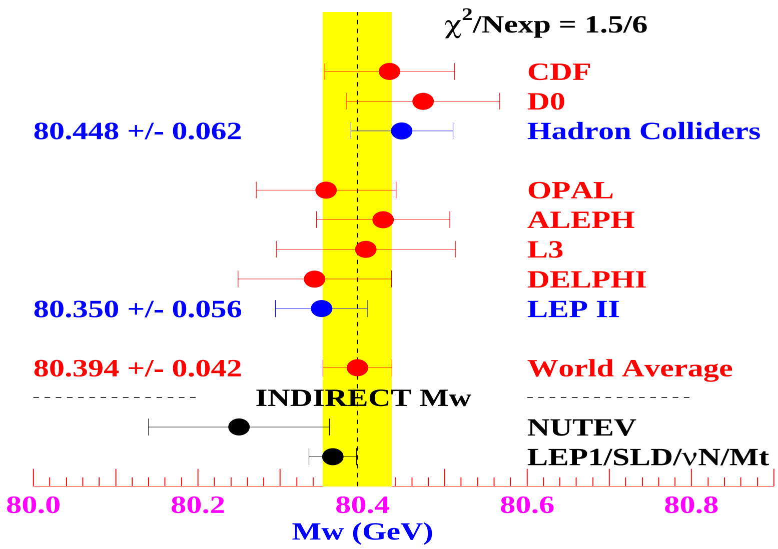

Figure 5. The direct determinations of the W mass from the Tevatron and LEP2 experiments are compared with the indirect measurement from NuTeV and the prediction based on fits to existing electroweak data.

The precision of these measurements has increased the sensitivity that one now has to the mass of the Higgs Boson. Indeed now it is the uncertainty on the top quark mass that is now becoming the limiting factor in the determiniation of the Higgs mass. As figure 6 shows, the available data tends to favour a Higgs boson with a mass < 250 GeV.

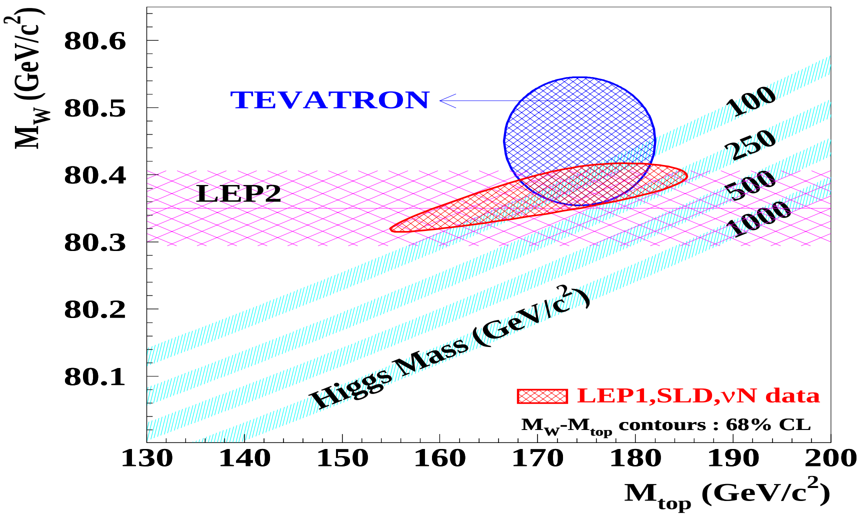

Figure 6. The direct measurements of the W boson and top quark mass from the Tevatron experiments are compared to the W mass measurements from LEP2 and the predictions based on electroweak fits to LEP1/SLD/νN data. The SM predictions for the Higgs mass as a function of the W and top masses are also shown.

6 Width Measurement

The W width can be determined in two ways. Firstly, from a direct measurement of the W mass distribution and secondly, indirectly, from a measurement of the W branching ratios. Presently, it is the indirect measurements which have the greater precision, but at the expense of the determination having a theory dependence, since the indirect measurements are converted to a width assuming the Standard Model. The direct measurement are presently limited by the statistical uncertainty. The LEP experiments perform a 2 parameter, $\mathrm{M_w}$, Γ_w, likelihood fit to the invariant mass distributions to determine Γ_w. The correlation between the fitted $\mathrm{M_w}$ and Γ_w is small. The LEP2 results give a direct Γ_w of 2.12 ± 0.2 GeV. This is only based on ~ 25 % of the total integrated luminosity, consequently a substantial improvement in the precision is anticipated.

The Tevatron experiments determine the width by a one parameter likelihood fit to the high transverse mass end of the transverse mass distribution. Detector resolution effects fall off in a Gaussian manner such that at high transverse masses ($\mathrm{M_T} \gtrsim 120$ GeV), the distribution is dominated by the Breit-Wigner behaviour of the cross section (see figure 7). In the fit region, CDF has 750 events, in the electron and muon channels combined.

At LEP2, the W branching fractions are determined by an explicit cross section measurement whilst at the Tevatron they are determined from a measurement of

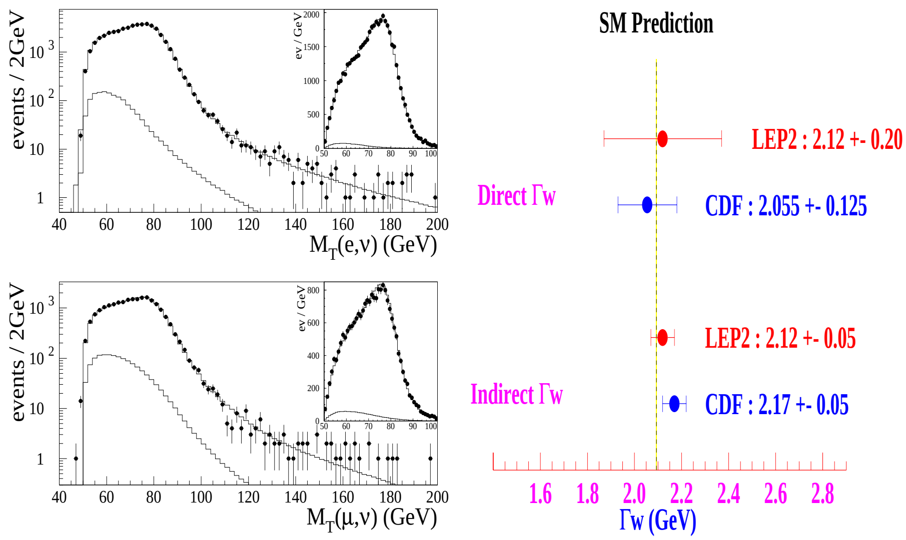

Figure 7. LEFT: The transverse mass distribution of the CDF $W \to e\nu$ (upper) and $W \to \mu\nu$ (lower) data showing the events at high transverse mass from which the W width is determined. (b) A comparison of the direct and indirect W width determinations from LEP and the Tevatron. The LEP indirect determination has been based on the $W \to e\nu$ branching fraction only.

a cross section ratio. Specifically, the W branching fraction can be written as : $\frac{\Gamma(W\to e\nu)}{\Gamma(W)} = \frac{\sigma_W}{\sigma_Z} \cdot \frac{\Gamma(Z\to ee)}{\Gamma(Z)} \cdot \frac{1}{R}$; where $R = \frac{\sigma_W \cdot Br(W\to e\nu)}{\sigma_Z \cdot Br(Z\to ee)}$ is the measurement made at the Tevatron. This determination thus relies on the LEP1 measurement of the Z branching fractions and the theoretical calculation of the ratio of the total Z and W cross sections. The indirect Tevatron measurement, $\Gamma_\mathrm{w} = 2.171 \pm 0.051$ GeV, is now becoming systematics limited. In particular, the uncertainty due to QED radiative corrections in the acceptance calculation and in $\frac{\sigma_W}{\sigma_Z}$ contributes 0.040 GeV to the total systematic uncertainty of 0.047 GeV in the indirect W width determination. The corresponding measurement from LEP2, using only the $W \to e\nu$ branching fraction, is $\Gamma_\mathrm{w} = 2.120 \pm 0.050$ GeV.

7 Conclusions

The Tevatron and LEP2 experiments now for the first time have W mass measurements with errors < 100 MeV per experiment. The determinations from the two colliders are in excellent agreement and show no deviation from the Standard Model expectations. These measurements when combined with other electroweak measurements have a predeliction for a Higgs boson of mass < 250 GeV. Further significant reductions in the W mass error will require progress to be made on a number of issues e.g. final state interactions at LEP2. The W width measurements are presently limited by the statistical uncertainty, but, again, are in good agreement with the Standard Model.

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